Seasonal Abundance and Diversity of Aphids (Homoptera: Aphididae) in a Pepper Production Region in Jamaica

SHARON A. McDONALD, SUSAN E. HALBERT,[1] SUE A. TOLIN,[2] AND BRIAN A. NAULT[3]

Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

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ABSTRACT Seasonal dispersal and diversity of aphid species were monitored on pepper farms in St. Catherine, Jamaica throughout 1998 and 1999 to identify the most likely vectors of tobacco etch virus (TEV) in pepper fields. Flight activity was monitored weekly on five farms using water pan traps. More than 30 aphid species were identified, 12 of which are new records for Jamaica. Ninety-two percent of the aphids captured from October 1998 through July 1999 belonged to only seven of the >30 species identified. Of these seven species, *Aphis gossypii* Glover and those in the *Uroleucon ambrosiae* (Thomas) complex comprised more than two-thirds of the total. Five known vectors of TEV were captured: *A. gossypii*, *Aphis craccivora* Koch, *Aphis spiraecola* Patch, *Myzus persicae* (Sulzer), and *Lipaphis pseudobrassicae* Davis. Generally, more aphids were collected from mid-September through mid-May than from mid-May through mid-September. The influence that rainfall and temperature had on periods of aphid flight activity also was investigated. Results indicated that flight of some species increased 3–4 wk after a rainfall event, whereas temperature did not appear to affect flight activity. High populations of *A. gossypii* as well as the presence of four additional known TEV vectors were encountered in October and November, which is the period that significant acreage is transplanted to pepper for harvest to coincide with the winter export market. Because pepper is most vulnerable to yield loss when young plants become infected with TEV, pepper production in Jamaica may be threatened if commonly abundant species such as *A. gossypii* are carrying TEV. Based on this information, implications for management of pepper viruses and their aphid vectors in Jamaica are discussed.

KEY WORDS aphids, seasonal abundance, *Potyvirus*, tobacco etch virus

PEPPERS, *Capsicum* spp., are grown in Jamaica throughout the year, and most fields eventually become diseased with viruses (McGlashan et al. 1993, Myers 1996, Martin et al. 1998), most of which are transmitted by aphids. The aphid-transmitted tobacco etch virus (TEV) (Genus: *Potyvirus*, Family: Potyviridae) is the most frequently encountered potyvirus in pepper fields in Jamaica (McGlashan et al. 1993, Myers 1996, Martin et al. 1998) and this virus has been shown to significantly reduce fruit yield and quality (McDonald 2001). At least 12 species of aphids are known to transmit TEV (Eckel and Lampert 1993). To date, a total of 26 aphid species have been recorded from Jamaica (Frank and Bennett 1970, Smith and Cermeli 1979, Murray 1985, Jayasingh 1996, Nafría et al. 1994), some of which transmit TEV. However, none of these aphids were reported to have been collected from pepper fields in Jamaica, with the exception of *Aphis gossypii* Glover (Myers et al. 1998), long known as a vector of TEV (Laird and Dickson 1963). It is not known how many other aphid vectors of TEV migrate into pepper fields in Jamaica.

The aphids most important in transmitting viruses to a crop are often not those that colonize the crop, but are those that happen to land in the field in search of a suitable host (Abney et al. 1976, Halbert et al. 1981, Halbert et al. 1994, Eckel and Lampert 1993, McDonald 2001). In addition to their feeding behavior, the migratory habits of aphids make them important in transmitting plant viruses over a range of distances. Peak aphid flights and the presence of known vectors are often associated with rapid spread of viruses in a particular area (Halbert et al. 1981, Shultz et al. 1985, Halbert et al. 1994, DiFonzo et al. 1997). In some instances, virus incidence has been correlated with high numbers of inefficient vectors when numbers of efficient vectors were low (Halbert et al. 1981, Shultz et al. 1985, DiFonzo et al. 1997). Therefore, the epidemiology of TEV and other nonpersistently aphid-transmitted viruses in pepper fields will be better

[1] Division of Plant Industry, Florida Department of Agriculture and Consumer Services, P.O. Box 147100, Gainesville, FL 32614–7100.

[2] Department of Plant Pathology, Physiology and Weed Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061–0330.

[3] Department of Entomology, Cornell University, New York State Agricultural Experiment Station, Geneva, NY 14456 (e-mail: ban6@cornell.edu).

understood once the aphid species that frequently migrate into pepper and their ability and efficiency in transmitting these viruses have been identified.

Seasonal abundance of aphids is better documented in temperate than in tropical regions. For example, Shaunak and Pitre (1971) identified two major flight periods for aphids in northeastern Mississippi. There was one peak flight between April and May and another between October and November when aphids moved from overwintering to summer hosts and vice versa. The timing of major flights often remains the same from year to year (Halbert et al. 1981, Eckel and Lampert 1996, DiFonzo et al. 1997), even though the species composition may change (Halbert et al. 1981, DiFonzo et al. 1997). In cold temperate regions, aphids often exhibit a heteroecious holocyclic life cycle. In contrast, aphids in the tropics tend to exhibit an anholocyclic life cycle, whereby they reproduce parthenogenetically on secondary hosts throughout the entire year (Eastop 1957, Blackman 1974). Aphid populations in the tropics are relatively stable and low throughout the year compared with those in temperate regions (Migliori et al. 1977, Bécquer Hernández and Fernándiz Puga 1981, Perez and Robert 1984, Perez and Garcia 1992, Sánchez et al. 1993, Sánchez et al. 1997).

Despite the relative consistency in weather conditions year round in tropical maritime regions, aphid populations have been reported to fluctuate as a result of subtle changes in temperature (Perez and Robert 1984, Sánchez et al. 1997, Michaud and Browning 1999), relative humidity and rainfall (Bécquer Hernández and Fernándiz Puga 1981, 1983; Sánchez et al. 1997). For example, Perez and Robert (1984) did not collect *Myzus persicae* (Sulzer) in Cuba when the maximum temperature exceeded 31°C. Also in Cuba, Bécquer Hernández and Fernándiz Puga (1981, 1983) reported a negative correlation between relative humidity and numbers of all developmental stages of aphid populations on *Phaseolus vulgaris* L., whereas alate *Uroleucon ambrosiae* (Thomas) populations on *Parthenium hysterophorus* L. increased after the rainy season. Perez and Robert (1984) also caught more alate aphids in yellow traps after the rainy period in Cuba. Rain might affect aphid populations indirectly by stimulating new growth in crops and weeds, which aphids find favorable for reproduction (Eastop 1957, Duviard and Pollet 1973).

Knowledge of seasonal abundance of aphids that transmit nonpersistent viruses such as TEV and how their activity may be affected by changes in environmental conditions and proximity of alternate hosts are important for predicting periods of high flight activity in pepper fields in Jamaica. With this information, farmers can schedule planting dates of pepper so that the presence of vulnerable plants is synchronized with the lowest period of TEV-vector flight activity. Additionally, alternative crops and weed hosts for these aphids located within or near pepper fields could be better managed. In this study we sought to identify (1) commonly encountered aphids that are known or could be potential TEV vectors, (2) periods of low aphid flight activity, especially those known as TEV vectors, and (3) abiotic and biotic factors that might affect aphid flight activity in a major pepper-producing region in Jamaica.

Materials and Methods

Fields Sampled, Sampling Technique, and Aphid Identification. Aphid flight activity was monitored on five pepper farms in St. Catherine parish, Jamaica from 13 February 1998 through 9 December 1999 (Fig. 1). With the exception of Farm 2, which was a pure stand of *Capsicum chinense* Jacquin, all the farms had a mixture of *Capsicum* spp. and some other crops. Plantings of all crops ranged from 0.04 to 0.7 ha. Farm 1 had plantings of *Allium cepa* L. (onion), *Zea mays* L. (corn), *Hibiscus cannabinus* L. (kenaf), and *Ipomea batatas* L (sweet potato). Farm 2 was bordered by *Abelmoschus esculentus* L (okra). Farm 3 had plantings of *Amaranthus dubius* Martius ex Thellung (spleen amaranth or callaloo), *Amaranthus esculentus*, *Cajanus cajan* (L.) (pigeon peas), and *Lycopersicon esculentum* Miller (tomato), whereas on Farm 4 *Solanum melongena* L. (eggplant), *Brassica oleracea* L. (cabbage), *Cucumis* spp., and *Momordica* spp. were grown. Farm 5 included *Amaranthus dubius*, *Cucurbita pepo* L. (pumpkin), and *L. esculentum.* Weeds were abundant on all farms throughout the year and were especially common after high rainfall events. Rainfall and minimum and maximum temperatures were recorded daily from a weather station on Farm 1 and weekly from a weather station on Farm 3.

On each farm, three water pan traps were placed 10 m apart in a diagonal pattern across a pepper field. Each trap consisted of a green plastic flower saucer (Thermo-Plastic [Jamaica] Ltd., Spanish Town; 22.9 cm in diameter) mounted on a wire frame. Saucers were painted with two shades of green (cobalt green HO56 and green gold HO86 acrylic paints, FINEST, Grumbacher, Bloomsbury, NJ) to create a mosaic pattern to mimic colors of pepper leaves (McDonald 2001) that might reduce selective attraction of aphid species to the traps.

Four holes (0.7 cm in diameter) were drilled 1 cm from the top of each saucer and covered with cloth (pore size $\leq$0.5 mm^2) to allow excess fluid to drain from the traps after rainfall and overhead irrigation events. The height of pan traps was adjusted to the level of the plant canopy. Saucers were filled with $\approx$250 ml each of monoethylene glycol and water (1:1) (modified from DiFonzo et al. 1997), which was collected and replenished weekly. Aphids were removed from the collection fluid, counted, and stored in 70% ethanol until identified to species. Most of the aphids collected were identified by S. Halbert, and others were identified by D. Voegtlin. Remaining specimens were identified by S. McDonald with the aid of museum specimens obtained from previously collected samples (identified by S. Halbert) and according to Smith et al. (1963) and Kono and Papp (1977). Voucher specimens are located at the Institute of Jamaica, Kingston.

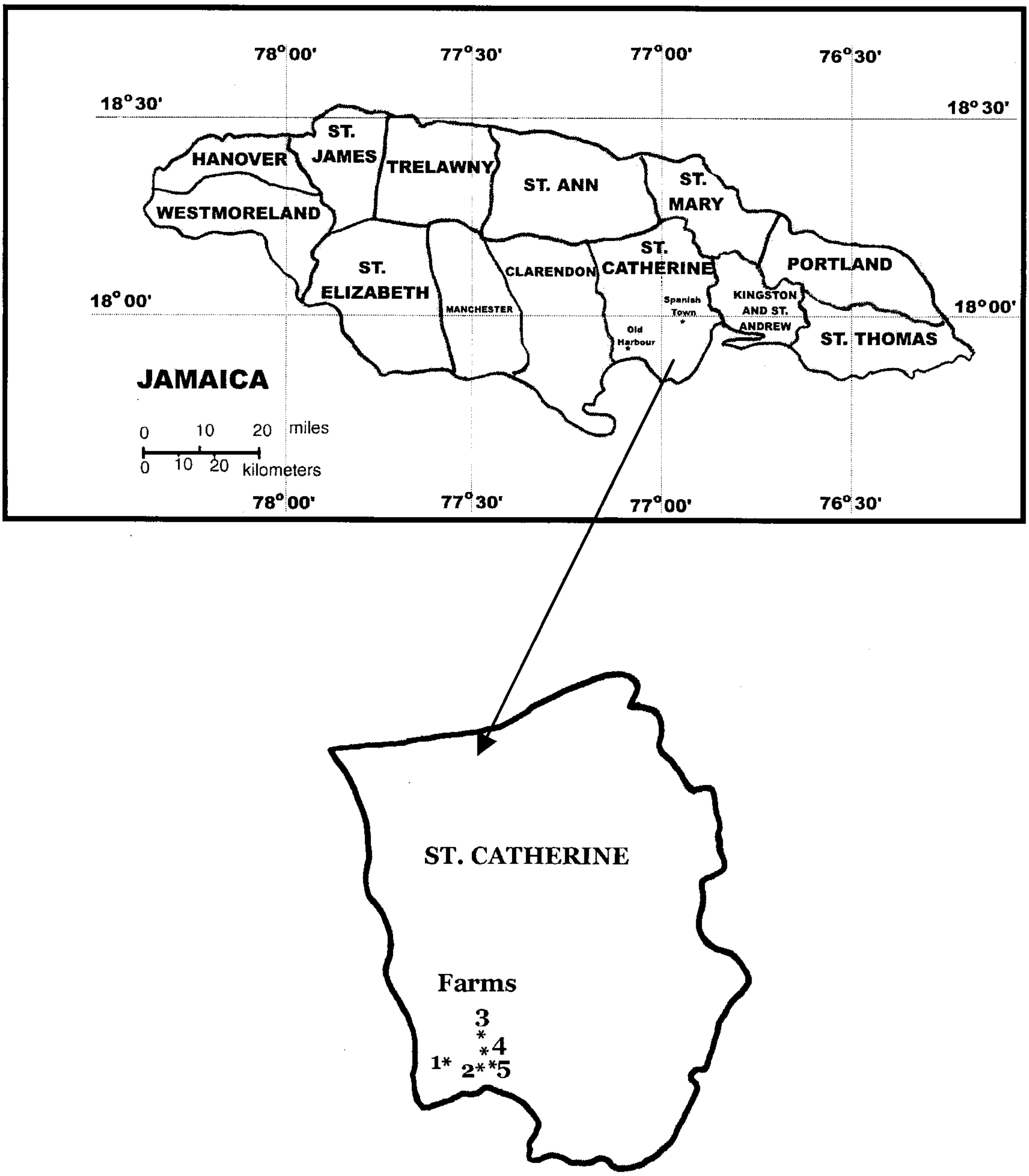

Fig. 1. Location of Farms 1 through 5, in St. Catherine, Jamaica, where aphids were captured. Farm 1 was in Bodles and Farms 3 and 4 were in Bushy Park.

Statistical Analyses. Because continuous data were not collected on all farms during the 2-yr sampling period, some analyses were limited to data from Farms 1, 3, and 4 from February 1998 through August 1999 (for number of aphids). Additionally, analyses of data on number of individual aphid species captured were limited to the period from October 1998 through July 1999. The effects that time, farm location, and their interaction had on the abundance of aphids collected were determined using time series analysis of variance (ANOVA) at $P < 0.05$ (MIXED DATA procedure, SAS Institute 1996). Using information obtained from the time series analyses, ANOVA at $P < 0.05$ was conducted to determine the effect of seasons on the number of aphids caught on all five farms (GLM procedure, SAS Institute 1996). The number of aphids per trap was averaged within a "season" and each season was repeated within a 2-yr period (Season A = February 1998 through mid-May 1998 and mid-September 1998 through mid-May 1999; Season B = mid-May 1998 through mid-September 1998 and mid-May 1999 through August 1999). Mean numbers of aphids

Table 1. Seasonal diversity of aphid species collected from water pan traps on five pepper farms in St. Catherine, Jamaica, W.I. and total number of each aphid species collected from four of these farms from October 1998 through 9 December 1999

Aphid	1998										1999											
	Feb/Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aphis amaranthi Holman[a]	[b]	[b]	[b]			[b]		3	0	3	25	18	28	84	26	20	2	0	0	1	1	2
Aphis craccivora Koch		[b]			[b]		[b]	4	3	18	7	19	12	3	6	1	1	1	1	2	2	3
Aphis gossypii Glover	[b]	[b]			[b]	[b]	[b]	428	130	122	52	47	44	87	32	40	12	6	28	16	4	3
Aphis nerii Boyer de Fonscolombe		[b]			[b]		[b]	1	4	8	3	13	17	7	0	3	2	0	2	1	0	0
Aphis spiraecola Patch		[b]			[b]		[b]	8	3	19	13	10	34	22	43	2	2	3	1	0	0	0
Aphis sp./unknown	[b]	[b]						2	0	0	2	1	1	2	6	2	0	0	0	2	0	0
Brachycaudus helichrysi (Kaltenbach)[a]		[b]						0	0	1	6	1	3	2	2	0	0	0	0	0	0	0
Lipaphis pseudobrassicae Davis[a]								0	0	3	13	10	11	2	1	0	0	0	0	0	0	0
Melanaphis sacchari (Zehntner)								4	2	1	1	1	0	1	0	3	0	0	0	1	0	0
Sipha flava (Forbes)	[b]	[b]	[b]	[b]	[b]		[b]	3	2	3	2	8	6	3	1	2	0	0	0	0	0	0
Tetraneura nigriabdominalis (Sasaki)								4	4	6	8	9	10	17	25	19	14	0	0	0	0	0
Toxoptera citricida (Kirkaldy)								0	0	2	1	2	6	9	2	2	1	0	2	0	1	0
Uroleucon ambrosiae (Thomas)[a] complex								0	0	68	517	11	16	94	16	20	5	4	0	1	1	0

[a] New species record for Jamaica.
[b] Species collected but number not recorded.

caught within seasons were compared for each farm (ANOVA at $P < 0.05$).

The diversity of aphid species collected from farms from October 1998 through July 1999 was determined using the Shannon-Weaver diversity index (H′) (see Price 1997),

$$H' = -\Sigma(p_i{*}\ln(p_i + 1 \times 10^{-13})) \qquad [1]$$

where p_i is the proportion of the *i*-th species of the total number of aphids collected each month. The value 1×10^{-13} was included to account for zero values in the equation

To identify an association between weekly aphid flight activity of the most commonly encountered aphid species and either total rainfall per week or mean weekly maximum and minimum temperatures, correlation coefficients (r) were generated using a time series cross correlation analysis at $P < 0.05$ (ARIMA procedure, SAS Institute 1996). Cross correlation analysis determines if correlation exists between the amount of rainfall or the minimum or maximum temperature recorded at week x and aphid numbers at week x, weeks x ± 1, x ± 2, etc. The relationship is considered significant at ≥ two standard errors (equivalent to $P \leq 0.05$). Significant correlations <1 wk or >4 wk were considered nonbiologically significant and have been omitted from the results. Correlations were made between weather data from Farm 1 and aphid flight data from Farm 1, whereas correlations were made between weather data from Farm 3 and aphid flight data from Farms 3 and 4, which were <1 km apart.

Results

Aphid Species Identified. More than 3,880 aphids were collected from traps from February 1998 through December 1999. More than 30 aphid species were identified, 12 of which are new records for Jamaica. Aphid species in which >10 individuals were captured during the sampling period are listed in Table 1. Species in which <10 individuals were captured during the season include the following: *Aphis coreopsidis* Thomas, *Capitophorus hippophaes* (Walker), *Geopemphigus floccosus* (L.), *Hysteroneura setariae* (Thomas), *Macrosiphum* sp., *M. persicae* (Sulzer), *Myzus* sp., *Pentalonia nigronervosa* Coquerel, *Rhopalosiphum maidis* (Fitch), *Rhopalosiphum padi* (L.), *Rhopalosiphum rufiabdominalis* (Sasaki), *Schizaphis graminum* (Rondani), *Schizaphis rotundiventris* (Signoret), *Toxoptera aurantii* (Boyer de Fonscolombe), *Trichosiphonaphis polygoni* (van der Goot), *Uroleucon pseudambrosiae* (Olive), and a species each from the Fordini and Mizini tribes. Of these, *C. hippophaes, G. floccosus, H. setariae, R. padi, S. graminum, S. rotundiventris, T. polygoni, U. pseudoambrosiae* and the species from the Fordini tribe and Mizini tribe are new record species for Jamaica. At least 15 aphid species were collected from traps on Farms 1 and 5, and >20 species collected from Farms 3 and 4. At least five species were collected on Farm 2.

Ninety-two percent of all aphids captured from October 1998 through December 1999 represented only seven of the >30 species identified (see Table 1). The most commonly encountered species were *A. gossypii* (40% of total), the *U. ambrosiae* (Thomas) complex (29% of total), *Aphis amaranthi* Holman (8% of total), *A. spiraecola* Patch (6% of total), *Tetraneura nigriabdominalis* (Sasaki) (4% of total), *A. craccivora* Koch (3% of total), and *A. nerii* Boyer de Fonscolombe (2% of total). Of these species, *A. gossypii, A. craccivora,* and *A. spiraecola* are known vectors of TEV (Laird and Dickson 1963, Herold 1970). Two additional TEV vectors were encountered, *M. persicae* and *Lipaphis pseudobrassicae* (Laird and Dickson 1963, Eckel 1990, Eckel and Lampert 1993), but represented <1% and 1.5% of the total number of aphids sampled.

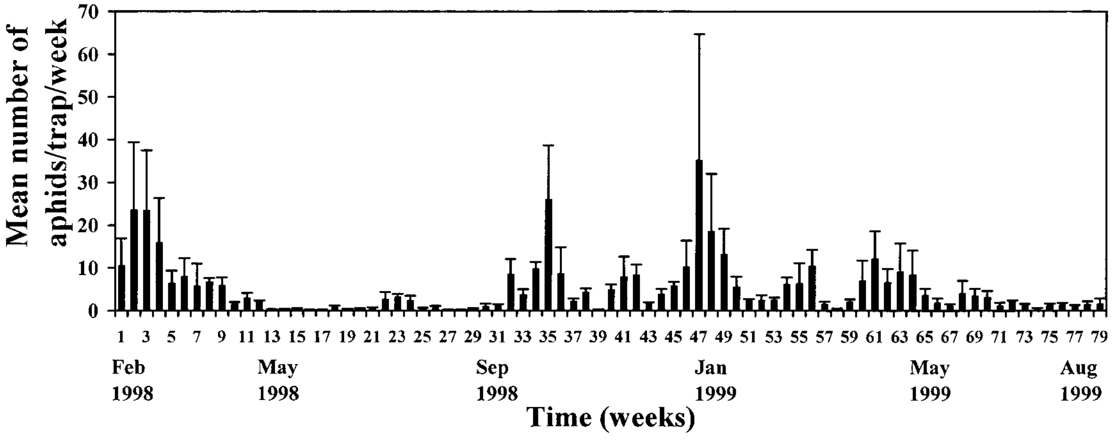

Fig. 2. Mean (±SEM) number of aphids collected in water pan traps each week on farms in St. Catherine, Jamaica, during 13 February 1998 through 18 August 1999. Weeks represent time after sampling was initiated in early February 1998.

Aphid Flight Activity. Overall, aphid flight activity varied significantly over time ($F = 5.83$; df = 1, 77; $P < 0.0001$), among farms ($F = 26.92$; df = 1, 2; $P < 0.0001$) and was highly affected by a farm by time interaction ($F = 3.69$; df = 1, 153; $P < 0.0001$). Aphid flight activity from mid-September through mid-May tended to be greater than activity between mid-May and mid-September (Fig. 2; Table 2). This trend was significant on across all farms ($F = 35.34$; df = 1, 38; $P < 0.0001$), except for Farm 2 (Table 2). The mean number of aphids captured per trap on Farms 1–5 from mid-September through mid-May were 4, 2, 6, 9, and 3 times greater than the numbers captured from mid-May through mid-September, respectively (Table 2).

Aphid species known to transmit TEV represented at least one-half of the total number of commonly encountered aphids captured each month from October 1998 through July 1999, with the exception of January 1999 (Fig. 3). Similarly, the four commonly encountered species with unknown status as TEV vectors often represented a majority of the remaining total number of aphids sampled. Known TEV vectors constituted 98% of the commonly encountered species in October and November 1998, whereas the four other commonly encountered species accounted for 84% of the total number of aphids trapped in January 1999 (Fig. 3).

Table 2. Mean (±SEM) number of aphids captured in water pan traps during periods of high and low flight activity on five pepper farms in St. Catherine, Jamaica, W.I.

Farm	High flight activity: mid-September to mid-May (number of aphids per trap per week)	Low flight activity: mid-May to August/mid-September (number of aphids per trap per week)
1	2.0 ± 0.3a	0.5 ± 0.1b
2	1.6 ± 0.3a	0.8 ± 0.3a
3	10.5 ± 1.3a	1.7 ± 0.4b
4	12.2 ± 2.6a	1.4 ± 0.4b
5	3.4 ± 0.5a	1.2 ± 0.1b

Data represent similar periods in 1998 and 1999. Means within the same row followed by different letters are significantly different (ANOVA, $P \leq 0.05$).

On Farm 1, aphid activity was highest from 25 November through 2 December 1998 (13 ± 1) and lowest from 14 May through 17 September 1998 (range: 0–2 ± 1) and again from 12 May through 18 August 1999 (range: 0–1 ± 1). *A. gossypii* was the most abundant species captured during the period of high flight activity.

On Farm 2, there was no outstanding variation in aphid flight over the period that data were collected. The mean number of aphids per trap per week ranged from 0 to 5 ± 3.

There were two periods in which the mean number (±SEM) of aphids captured per trap per week was high on Farm 3. These periods were 7 through 14 October 1998 (37 ± 2) and 22 December 1998 through 20 January 1999 (range: 22 ± 5–94 ± 37). *A. gossypii* and the *U. ambrosiae* complex predominated each period, respectively. *A. gossypii*, the *U. ambrosiae* complex, and *A. amaranthi* also were the predominant species during the first week of March 1998 (total mean number per trap per week = 19 ± 4) and in April 1999 (range: 17 ± 1–25 ± 8 total number of aphids per trap per week). Few aphids were trapped from mid-May through mid-September 1998 (range: 0–6 ± 4 aphids per trap per week) and from mid-May through August 1999 (range: 0–5 ± 1 aphids per trap per week).

Aphid flight activity was high on Farm 4 from February through March 1998 (range: 23 ± 2–55 ± 19 aphids per trap per week) and from 7 through 21 October 1998 (range: 21 ± 10 and 41 ± 8 aphids per trap per week). *M. persicae* and *A. gossypii* dominated the species captured during each period, respectively. Conversely, few aphids were captured from 14 May through 17 September 1998 and from 12 May through 18 August 1999 (range: 0–6 ± 4 and 0–5 ± 1, respectively).

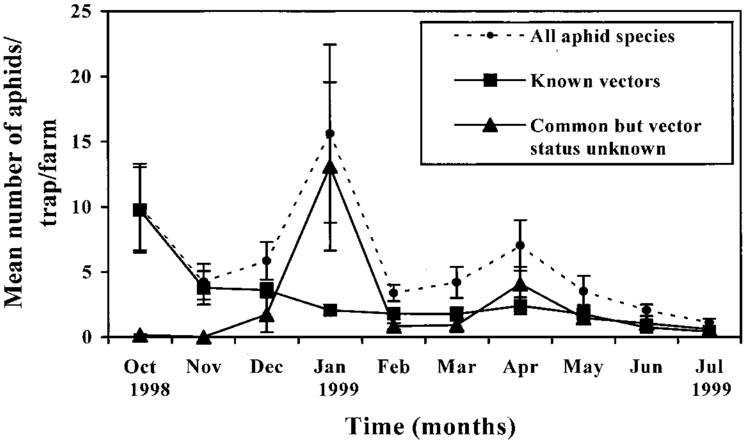

Fig. 3. Mean (±SEM) number of aphids, number of aphids known as TEV vectors, and number of common aphid species with unknown TEV vector status collected in water pan traps on pepper farms in St. Catherine, Jamaica, W.I. from October 1998 through August 1999. Known vectors of TEV include *Aphis gossypii*, *A. craccivora*, *A. spiraecola*, *Lipaphis pseudobrassicae*, and *Myzus persicae*. Commonly encountered species with unknown TEV vector status are *Aphis amaranthi*, *Tetraneura nigriabdominalis*, and those in the *Uroleucon ambrosiae* complex.

On Farm 5, aphid flight activity was high from 3 through 10 March 1999, when the mean number of aphids caught per trap was 12 ± 1. *A. gossypii* and *A. nerii* accounted for most of the aphids captured at that time. Aphid activity was low from 12 May through 18 August 1999 (range: 0–5 ± 4 aphids per trap per week).

Aphid Species Diversity within Farms. On Farm 1, the lowest species diversity occurred in October 1998, when *A. gossypii* accounted for 80% of the total catch (Table 3). The next lowest species diversity occurred in July 1999, when *T. nigriabdominalis* comprised 60% of the total number of aphids captured. The highest species diversity occurred during February 1999, followed by April then March 1999, when no species was dominant.

On Farm 3, the lowest species diversity occurred in November 1998, then October 1998 and January 1999, respectively (Table 3). *A. gossypii* represented 91% and 90% of all aphids captured in November and October 1998, respectively, whereas *U. ambrosiae* complex accounted for 85% of the total catch in Jan-

Table 3. Shannon-Weaver Diversity Index (H′), total number of aphids, and number of aphid species captured in water pan traps on four farms in St. Catherine, Jamaica during October 1998 through July 1999

Location	Oct 98	Nov 98	Dec 98	Jan 99	Feb 99	Mar 99	Apr 99	May 99	Jun 99	Jul 99
Farm 1										
Diversity Index	0.83	1.13	1.23	1.58	1.92	1.89	1.90	1.67	1.55	0.95
Total aphids	49	19	75	17	25	20	27	11	7	5
No. species	7	5	9	7	9	8	11	6	5	3
Farm 3										
Diversity Index	0.51	0.41	1.26	0.69	1.86	1.86	1.55	2.06	1.65	1.61
Total aphids	175	47	125	508	50	66	229	93	26	10
No. species	10	5	10	13	11	10	12	13	7	6
Farm 4										
Diversity Index	0.27	0.54	1.54	1.07	1.87	2.52	1.92	1.63	1.37	1.38
No aphids	242	85	58	121	38	49	55	26	60	13
No. species	8	6	11	8	11	16	10	6	8	5
Farm 5										
Diversity Index	ND[a]	ND	ND	1.00	1.55	2.07	1.94	1.75	1.52	1.36
Total aphids	ND	ND	ND	7	34	65	26	36	24	12
No. species	ND	ND	ND	3	8	14	8	8	6	5
All 4 farms										
Diversity Index	0.48	0.68	1.60	0.92	2.30	2.36	1.82	2.03	1.88	1.71
Total aphids	466	151	258	653	148	198	337	164	117	40
No. species	14	9	16	16	19	20	18	35	13	9

[a] ND = no data.

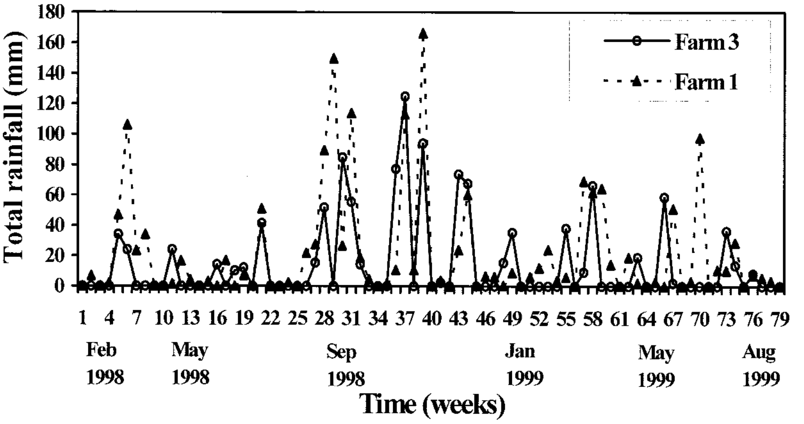

Fig. 4. Total weekly rainfall (mm) amounts on Farms 1 and 3 recorded from 13 February 1998 through 18 August 1999.

uary 1999. Species diversity was highest during May, then during February and March 1999.

The lowest species diversity occurred during October then in November 1998 on Farm 4 (Table 3). *A. gossypii* comprised 95% and 88% of the total number of aphids captured, respectively. Species diversity was highest during March, then in April and February 1999, respectively.

On Farm 5, species diversity was lowest in January 1999 when *A. gossypii* and *Brachycaudus helichrysi* (Kaltenbach) each represented 43% of the total catch (Table 3). In contrast, species diversity was highest in March 1999 when no species was dominant.

Effects of Rainfall and Temperature on Flight Activity within Farms. At least one rainfall event was recorded every month during this survey, with the exception of June 1999 (Bushy Park, Fig. 4). Less than 20 mm of rainfall was recorded at both locations during January 1999 and in Bushy Park during April 1999. Generally, the wettest period occurred from September through December 1998 when more than 90 mm of rain fell each month. Aphid flight activity increased significantly after rainfall events on all farms (Farms 1, 3, and 4). Overall, on Farm 1 there was a 3-wk lag between a rainfall event and an increase in the mean number of aphids captured per trap per week (r = 0.59; N = 78). The numbers of five species including *A. gossypii* increased significantly 3 wk after a rainfall event (Table 4). Overall, on Farms 3 and 4, there was a 4-wk lag between a rainfall event and an increase in the mean number of aphids caught per trap per week (r = 0.29 and r = 0.23, respectively; N = 78). The numbers of two species including those in the *U. ambrosiae* complex increased significantly 3 and 4 wk after rainfall events, respectively (Table 4).

On Farm 1, mean monthly maximum temperatures ranged from 30°C (February 1999) to 34°C (June through August 1998) (Fig. 5). Mean monthly minimum temperatures ranged from 19°C (February 1998, March 1999 and February 1999) to 23°C (August and September 1998). The numbers of *S. flava* captured decreased significantly 1–3 wk after a change in either maximum or minimum temperature (Table 5). For species in the *U. ambrosiae* complex, the number captured per trap decreased significantly 1 and 4 wk after a minimum temperature was reached.

On Farms 3 and 4, mean monthly maximum temperatures ranged from 29°C (December 1998 and January 1999) to 34°C (May 1998) (Fig. 5). Mean monthly minimum temperatures ranged from 16°C (February 1998 and 1999) to 21°C (April 1998, 1999, and June 1999). Overall, there were no significant correlations

Table 4. Correlation ($P \leq 0.05$) between total rainfall per week and total number of aphids collected in water pan traps each week on pepper farms in St Catherine, Jamaica, W.I. during October 1998 through July 1999

Farm	Aphid species	Number of weeks (lag weeks) after weekly rainfall event in which aphid flight activity is correlated (N = 43)	Correlation coefficient (r)
1	*Aphis craccivora*	3	+0.57
	Aphis gossypii	3	+0.29
	Aphis spiraecola	3	+0.32
	Tetraneura nigriabdominalis	3	+0.46
	Toxoptera citricida	3	+0.40
3 and 4	*Aphis nerii*	3	+0.45
	Uroleucon ambrosiae complex	4	+0.28

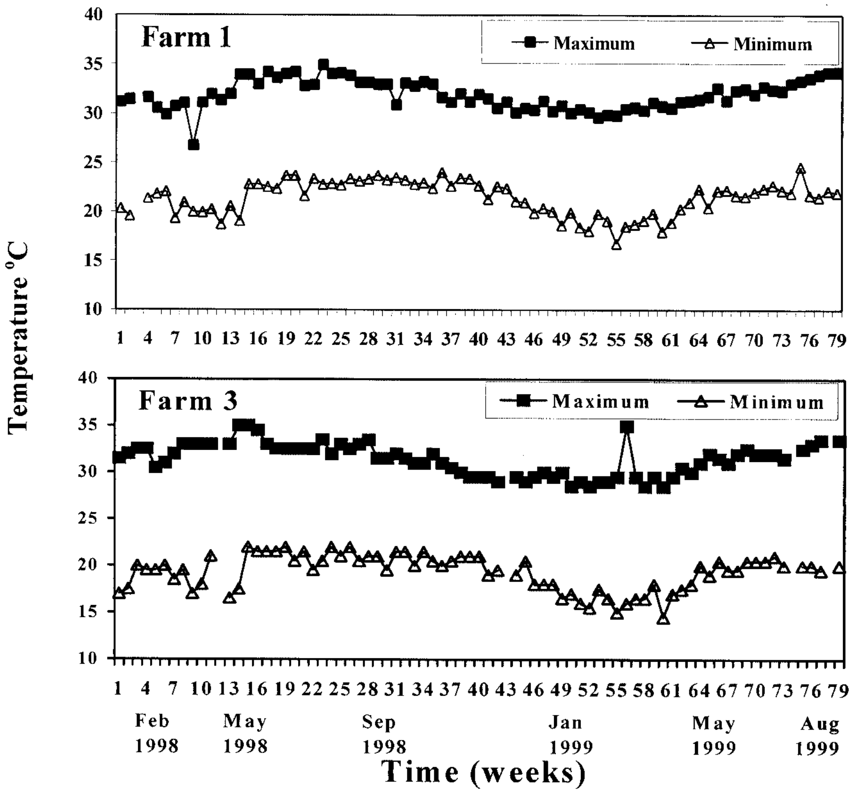

Fig. 5. Weekly minimum and maximum temperatures (°C) on Farms 1 and 3 recorded from 13 February 1998 through 18 August 1999.

between changes in temperature and a change in the total mean number of aphids captured per trap per week. For five species, however, the numbers of aphids captured decreased significantly 1–4 wk after either a change in maximum or minimum temperature (Table 5). For *A. gossypii,* the number captured per trap increased significantly 1 wk after a minimum temperature was reached.

Discussion

More than 30 aphid species were collected from pepper farms in this 2-yr survey, 12 of which are new records for Jamaica. Most of these species have been reported previously in Cuba and Puerto Rico (Smith et al. 1963, Smith and Cermeli 1979, Nafría et al. 1994), with the exception of *S. rotundiventris* and *T. polygoni. A. amaranthi* occurs in Cuba (Holman 1974) and is a pest of culinary amaranth. *C. hippophaes* and *U. pseudoambrosiae* are also found in Cuba. *B. helichrysi, G. floccosus, H. setariae, L. pseudobrassicae, R. padi, S. graminum,* and *U. ambrosiae* are found in Cuba and Puerto Rico (Smith and Cermeli 1979). *T. polygoni* and *S. rotundiventris* are relatively new to the Western

Table 5. Correlation ($P \leq 0.05$) between weekly maximum and minimum temperatures and total number of aphids collected in water pan traps each week on pepper farms in St Catherine, Jamaica, W.I. during October 1998 through July 1999

Farm	Aphid Species	Number of weeks (lag weeks) after maximum or minimum weekly temperature in which there is correlation with aphid flight activity (N = 43)			
		Maximum temperature (°C)		Minimum temperature (°C)	
		Weeks	Correlation coefficient (r)	Weeks	Correlation coefficient (r)
1	*Sipha flava*	1 to 3	−0.29 to −0.37	1 to 3	−0.29 to −0.42
	Uroleucon ambrosiae complex	—	—	1 and 4	−0.30 and −0.28
3 and 4	*Aphis amaranthi*	2 and 3	−0.35 and −0.41	1 to 4	−0.35 to −0.63
	Aphis craccivora	1 to 4	−0.30 to −0.37	—	—
	Aphis gossypii	—	—	1	+0.33
	Aphis spiraecola	3 and 4	−0.32 and −0.43	2 to 4	−0.29 to −0.49
	Lipaphis pseudobrassicae	1 to 4	−0.32 to −0.43	1 to 3	−0.32 to −0.46
	Tetraneura nigriabdominalis	—	—	4	−0.30

Temperatures were recorded daily and the weekly average calculated for Bodles whereas temperatures were recorded once weekly in Bushy Park.

Hemisphere and have been found in Florida (Halbert et al. 2000).

Ninety-two percent of the aphids captured during this study belonged to only seven of the >30 species identified. Of these seven species, *A. gossypii* and those in the *U. ambrosiae* complex comprised more than two-thirds of the total. Five known vectors of TEV were captured: *A. gossypii, A. craccivora, A. spiraecola, M. persicae,* and *L. pseudobrassicae* (Laird and Dickson 1963, Herold 1970, Eckel 1990, Eckel and Lampert 1993). The *Aphis* species were much more abundant than those from other genera. Further information is needed to determine whether the more abundant species collected can transmit and are efficient in transmitting viruses such as TEV to pepper.

In our study, numbers of aphids captured in traps during periods of relatively intense aphid flight activity in pepper fields were much lower than those captured during aphid flights in temperate regions (Halbert et al. 1981, DiFonzo et al. 1997). The mean number of aphids captured per trap per week was always <100 on all farms. However, aphid abundance did change significantly during certain periods of the year. Generally, more aphids were collected from mid-September through mid-May than from mid-May through mid-September. Similarly, during a 4-yr study in Cuba, Perez and Robert (1984) also reported greater aphid flight activity from the end of October to May than from mid-May to the end of October/early November. In a survey of aphids in sugar cane fields in north-central Venezuela, most winged aphids were captured during April and May, whereas the fewest were collected from July/August through October (Sánchez et al. 1993). In a 3-yr study in southern Florida, Wolfenbarger (1966) reported that the greatest number of aphids were captured from January through early May, whereas the least were caught in August and September.

The diversity of aphid species was lowest and highest during periods of highest and lowest flight activity, respectively. *A. gossypii* dominated the number of aphids captured from October through December 1998 and February and March 1999, whereas the *U. ambrosiae* complex dominated the species captured during January 1999 and April 1999. Although *A. gossypii* transmits TEV, the ability of species in the *U. ambrosiae* complex to transmit TEV is unknown; however, they are capable of transmitting several other potyviruses (Bécquer and Bencomo 1974, Bird et al. 1974, Abney et al. 1976, Koike 1977, Bécquer Hernández and Fernándiz Puga 1983, Orozco Santos et al. 1994). Farmers in St. Catherine grow pepper throughout the year, so if this species is a significant TEV vector, it could be a serious threat to pepper.

Farm management practices and crop and weed diversity likely influenced aphid abundance and species diversity on the farms sampled. Several crops were grown concurrently on Farms 3 and 4, whereas fewer crops were grown at the same time on the others. All farms became heavily infested with weeds during some period of the study. A large number of *M. persicae* was collected on Farm 4 during February and March 1998 when this aphid was observed colonizing pepper and adjacent *B. oleracea* plants. Large populations of *U. ambrosiae* were observed on *P. hysterophorus,* a weed that was common on all farms. *A. gossypii* often was observed colonizing pepper and is known to colonize a wide range of host plants found on and near pepper fields (Smith et al. 1963). *A. amaranthi* colonizes *Amaranthus* spp. (Smith and Cermeli 1979) and *T. nigriabdominalis* colonizes the roots of grasses (Smith et al. 1963), which form part of the weed community on all farms year round. Amaranths are grown commercially on Farms 3 and 4 and were common weeds on all farms throughout the year.

Crops and weeds in and around fields may affect the species composition of aphids and are often potential sources of virus inocula (Bos 1981). DiFonzo et al. (1997) identified several cultivated crops and volunteer plants in the Red River Valley of Minnesota and North Dakota that influenced the species composition of aphids caught on local potato farms. Sánchez et al. (1997) reported greater diversity of aphid species where more crops were grown and where weed and aphid management was minimal to nonexistent. Anderson (1959) identified 21 species of weeds as sources of viruses to which pepper was susceptible growing near pepper fields in Florida.

Rainfall affected the seasonal abundance of some aphid species on the farms. Positive correlations were observed between rainfall events and 3–4 wk delay in abundance of *A. craccivora, A. gossypii, A. spiraecola, A. nerii, T. nigriabdominalis, T. citricida,* and the *U. ambrosiae* complex. Sánchez et al. (2000) reported similar correlations between rainfall events and 2- to 4-wk delays in increased flights of *A. gossypii, A. nerii,* and *U. ambrosiae.* They found no correlation between rainfall and flight activity of *A. craccivora.* Bécquer Hernández and Fernándiz Puga (1983) reported positive correlations between rainfall events and numbers of nymphal and adult stages of *U. ambrosiae* on *P. hysterophorus.* In contrast to the results in our study, Sánchez et al. (2000) reported a negative correlation (3-wk lag) between a rainfall event and numbers of *A. spiraecola.* They did report a positive correlation between a rainfall event and a delay in numbers of *M. persicae.*

Flight activity of aphids responded variably to temperature. There were positive and negative correlations between changes in maximum and minimum temperatures and changes in aphid flight activity. Despite these significant relationships, we cannot offer a biological explanation for them. There is little information on the impact of temperature on flight of aphid species in the tropics.

High populations of *A. gossypii* as well as the presence of four additional known TEV vectors were encountered in October and November, which is the period that significant acreage in Jamaica is transplanted to pepper for harvest to coincide with the winter export market. Because yield of pepper fruit is most negatively affected when young plants become infected with TEV (McDonald 2001), pepper production in Jamaica may be threatened if *A. gossypii* and other aphid vectors are carrying TEV. Therefore, farmers might need to consider implementing strict virus-free management practices at this time (e.g., protect seedlings with aphid-impermeable netting before transplanting, use stylet oils, remove weeds within or adjacent to pepper fields and destroy old pepper fields that may harbor TEV and its vectors). Alternatively, farmers could transplant the pepper crop between mid-May and mid-September when abundance of migrating TEV vectors such as *A. gossypii* is very low, but such a planting time may not correspond well to market demand.

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